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LOW-TEMPERATURE CREEP CHARACTERISTICS OF Ti-5Al-2.5Sn and Ti-6Al-4V ALLOYS

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Roger J. Runck

Roger J. Runck
Director

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John A. VanEcho

An important design criterion for many structures is their creep characteristics. Creep is the time-dependent strain which occurs in a material under stress. It is often considered to be a high-temperature phenomenon which is not necessarily true. It is true that creep is more of a problem in high-temperature structures, but in some materials it must be taken into account in the design of ordinary and even low-temperature structures.

Most low-temperature structures are designed with stress limitations determined by the yield, ultimate, or fatigue strength. The impact and notch-strength properties may also be limiting factors. If each of these is satisfied and the material tends to creep, the design stress may very well be limited by the creep strength.

Design usually involves three types of strain; thermal, elastic, and plastic. Thermal strain is recoverable but must be considered if a substantial change in temperature is contemplated. Elastic strain is proportional to the stress and this process is also completely reversible. Plastic strain is essentially permanent with the exception of a very small recovery which for practical purposes is usually ignored. Plastic strain can be obtained in two ways: (1) instantaneously by exceeding the proportional limit, and (2) by maintaining a stress for a period of time. The latter, of course, is creep.

We are primarily concerned here with the time-dependent strain, or creep. Each of the other types of strain is perhaps equally important but will not be discussed here. We will, however, have to concern ourselves with elastic and instantaneous plastic strain, since it is difficult to isolate them completely from a discussion of creep. When a creep test is performed, an isothermal condition is assumed, and thermal strains are excluded from consideration. The load produces an elastic strain, which is proportional to the stress, and if above the proportional limit, some plastic strain. For titanium alloys, a relatively high stress is usually required to produce creep at low temperature. This often means that the proportional limit of the material has been exceeded, resulting in a certain amount of initial plastic strain. Therefore, creep may be important, but thermal, elastic, and instantaneous plastic strain cannot be excluded from design considerations.

This note is concerned solely with the low-temperature creep properties of the Ti-5Al-2.5Sn and Ti-6Al-4V alloys. In assessing these properties of these materials, it is important to note that a fairly wide spread in their tensile properties has been reported in the literature. This is particularly true for the Ti-6Al-4V alloy which can be heat treated to moderately high strengths. As a reference point in this discussion, Table 1 lists the tensile properties which are typical of those which are being achieved on current production material. Values are included for both the normal and "extra-low interstitial" (ELI) grades.

TABLE 1. TYPICAL ROOM-TEMPERATURE MECHANICAL PROPERTIES[1]

Alloy	Condition	UTS, 1000 psi	YS, 1000 psi	Elongation, %	RA %	PL, 1000 psi
			Normal Grade			
5Al-2.5Sn	Annealed	125	117	18	40	-
6Al-4V	Annealed	138	128	12	43	-
6Al-4V	Heat treated	170	155	8	54	147
			ELI Grade			
5Al-2.5Sn	Annealed	110	95	20	-	-
6Al-4V	Annealed	135	127	15	-	-

In the past, deviations as great as ±20 per cent from the Table 1 values have been reported for both alloys.[2] These deviations reflect earlier differences in processing histories as well as in the chemistry of individual heats. This wide latitude in tensile properties explains why, in several earlier studies at least, the creep stresses used in some instances exceed the yield and even ultimate strength values of current production material.

It was generally believed that the Ti-5Al-2.5Sn and Ti-6Al-4V alloys do not creep at room temperature. There may be some justification for this belief, again depending on the specific heat, the chemistry, the stress level, and processing variables of the particular lot of material. There is evidence, however, that the Ti-5Al-2.5Sn alloy does creep at room temperature, as shown by several investigators. Some creep tests on sheet material by North American Aviation, Inc.,[3] although limited to only three hours of test time, clearly show creep occurring at stresses of 100,000 to 120,000 psi (Table 2). Although it is difficult attempting to establish a minimum creep rate in such a short time, indications are that the creep rate at 100,000 psi is less than 0.005% per hour. Stresses in excess of typical yield and even ultimate strength values are noted.

TABLE 2. SHORT-TIME CREEP DATA FOR ANNEALED Ti-5Al-2.5Sn, 0.040-GAGE SHEET AT ROOM TEMPERATURE[3]

Stress, psi	Total Elongation for Indicated Time, per cent			
	0.05 hr	0.3 hr	1.0 hr	3.0 hrs
1[illegible]0,000	(5% in 0.03 hr)			
12[illegible],000	1.3	2.0	2.7	3.5
115,000	[illegible].1	1.2	1.2	1.3
105,000	0.95	0.95	0.95	0.97
100,000	0.87	0.91	0.92	0.93

Data obtained by Rem-Cru[4] on annealed Ti-5Al-2.5Sn alloy at room temperature show very similar results (Table 3). Here, the creep tests were conducted at stresses ranging from 90,000 to 115,000 psi for times long enough to establish a minimum creep rate. Room-temperature ultimate and yield strength property values for Heat No. R-2724 are 134,000 and 124,000 psi, respectively, obtained at a strain rate of 0.001 in./in./min. The proportional limit for this heat of material is 100,000 psi, the elongation is 18%, and the RA 48.8%.

In each of the above sets of data, the elastic strain can be calculated and subtracted from the total by using an elastic modulus of about 15.5×10^6 psi.

Some limited data from the Marine Engineering Laboratory[5] show the following properties of the Ti-5Al-2.5Sn alloy:

Yield Strength, psi	Creep Stress, psi	Yield Strength, %	Time, hrs	Creep, in./in.
		Tensile Creep		
123,400	97,100	79	664	0.0042
123,400	97,100	79	933	0.0081
		Compressive Creep		
137,000	100,600	73	1120	0.0086

Some fairly extensive creep data were supplied by North American Aviation[6] on ELI grade of the Ti-5Al-2.5Sn alloy. These data are shown in Table 4 for sheet, plate, and forging stock at room temperature and in the stress range of 64 to 92 per cent of the yield strength.

AiResearch[7] made some creep data available obtained from subzero (-320 F) tests on the

TABLE 3. SUMMARY OF ROOM-TEMPERATURE CREEP RESULTS ON ANNEALED Ti-5Al-2.5Sn (Heat No. R-2724)[4]

Test Stress, 10^3 psi	Total Def., %	Plastic Def., %	Test Duration, hr	Minimum Creep Rate, %/hr	Time to 1% Def., hr	Time to Rupture, hr	1% Def., T(20 log t)
115.0	19.5	19.5	41.6	0.19	0.05	41.6	10.1
110.0	19.5	19.5	339.6	0.019	0.15	339.6	10.35
105.0	5.7	4.82	1362.4	0.00075	5.0	-	11.2
100.0	3.3	2.5	1208.4	0.00050	20.0	-	11.5

TABLE 4. SUMMARY OF ROOM-TEMPERATURE CREEP DATA ON Ti-5Al-2.5Sn (ELI-GRADE) TITANIUM ALLOY[6]

Stress, psi	Yield Strength, %	Creep Strain in Time Given, per cent: 1 hr	10 hr	100 hr	500 hr	Final	Test Duration, hrs
			Sheet				
82,200	73.7	0.007	0.007	0.02	-	0.024	741
82,200	73.7	-	-	0.02	-	0.033	741
81,500	80.0			Negligible			156
86,500	85.0	-	-	-	-	0.07	156
92,000	90.0	-	-	-	-	2.03	156
			Plate				
82,500	77.0	-	-	-	-	0.1	23
84,500	79.0	-	-	-	-	0.2	24
86,500	81.0	-	-	-	-	0.4	24
89,000	83.1	-	-	-	-	0.5	23
91,000	85.0	-	-	-	-	1.5	23
			Forging				
74,600	64.7	-	-	0.023	0.04	0.05	742
80,700	70.0	0.015	0.04	0.08	-	0.12	360
87,100	75.5	0.06	0.15	0.23	0.31	0.33	600
87,100	75.5	0.025	0.08	0.14	0.23	0.24	[illegible]
90,000	80.4	-	-	-	-	1.1	23
90,000	83.4	-	-	-	-	3.1	25
90,000	78.3	-	-	-	-	2.4	24
90,000	83.4	-	-	-	-	Rupture	2.3
95,000	83.0	-	-	-	-	Rupture	62
95,000	83.0	-	-	-	-	6.0	46
99,500	86.2	0.07	0.17	0.33	0.51	0.53	600
[illegible]	91.6	0.5	-	-	4.75	Rupture	578

Ti-5Al-2.5Sn alloy sheet. Test procedures included the usual condition of reaching test temperature (-320 F) prior to loading the specimen. However, a deviation from normal creep-test procedure involved taking creep readings. It was necessary for the specimens to stabilize at room temperature for each strain reading. These data are summarized in Table 5.

TABLE 5. CREEP AND SHORT-TIME TENSILE PROPERTIES OF Ti-5Al-2.5Sn ALLOY AT -320 F[7]

Stress, psi	Yield Strength, %	Creep Strain in Given Time, % 1 hr	5 hr	10 hr	18 hr	50 hr
		Normal Grade*				
167,500	85	No measureable creep				
187,150	95	0.24	0.48	0.60	-	-
		ELI Grade				
153,600	85	0.165	0.660	0.975	1.08	1.08

Tensile Properties Before Creep Testing: Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation, %	Tensile Properties After Creep Testing: Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation, %
		Normal Grade*			
204,000	197,000	12	-	-	-
		ELI Grade			
188,670	180,670	17	199,000	192,000	17

* Composition of Normal Grade Material

Al - 5.23%	H_2 - 37 ppm
Sn - 2.60%	O_2 - 0.130%
Fe - 0.28%	C - 0.02%
Mn - 0.63%	N - 0.012%

Low-temperature creep data on the Ti-6Al-4V alloy are less prevalent than on the Ti-5Al-2.5Sn alloy. Since sufficient data are unavailable, it is not clearly evident to what extent the alloy creeps at low temperatures.

Some work by Mallory-Sharon[8] indicates that at stresses of 84,000 to 104,000 psi (60 to 75% of UTS), creep does occur in the Ti-6Al-4V alloy at room temperature. Most of the test specimens were prestressed about 10 per cent in excess of the creep stress prior to actual creep testing. The effect of the prestressing is not clearly shown. The creep rate seems to be rather independent of the stress as shown in Table 6 and in Figure 1. The reason for this may be that the extensometer had insufficient sensitivity. In fact, the reference[8] mentioned that greater sensitivity than was used would be needed for further tests.

Some further indirect evidence tends to show that the alloy does creep. Larson-Miller-type parameter curves prepared by Rem-Cru[9,10] give the following results:

Stress for 0.5% Plastic Strain in Indicated Time: 0.1 hr	10 hr	1000 hr
143,000 psi	138,000 psi	133,000 psi

Ultimate and yield strength values were not available for this lot of material. It is fairly evident, however, that the strength of this material was above what is now considered as typical for annealed material. No information is given that the data were obtained directly from room-temperature creep tests. It is possible that they were derived from higher temperature tests or from short-time tensile tests. Another source[11] gives the information that a stress of about 134,000 psi will produce "0.2% plastic creep" in 100 hours in the Ti-6Al-4V alloy sheet at 80 F. Indication was that the data were obtained from vendor sources.

TABLE 6. ROOM-TEMPERATURE CREEP OF Ti-6Al-4V ALLOY BAR[8]

Heat No.	Stress, psi	% Permanent Strain in 500 hr	1000 Hr	Creep Rate, %/hours	Ultimate Tensile Strength, psi	Yield Strength 0.2% Offset, psi
24273	104,000	0.01	0.02	0.00002	148,000	141,000
24273	104,000	0.01	0.03	0.00002	148,000	141,000
29176	104,000	0.005	0.005	0.00001	135,000	131,000
29176	104,000	0.32	0.38	0.00005	135,000	131,000
29176	91,000	0.06	0.09	0.00006	135,000	131,000
29176	91,000	0.12	0.15	0.00006	135,000	131,000
29176	84,000	0.16	0.18	0.00002	135,000	131,000
29176	84,000	0.14	0.21	0.00013	135,000	131,000
31151	104,000	0.25	0.36	0.00022	133,000	132,000
31151	104,000	0.25	0.37	0.00022	133,000	132,000
31151	91,000	0.02	0.025	0.00001	133,000	132,000
31151	91,000	0.03	0.03	-	133,000	132,000
31151	84,000	0.05	0.06	0.00002	133,000	132,000
31151	84,000	0.06	0.08	0.00004	133,000	132,000

(1) All specimens heat treated at 1300 F for 1 hour and AC.

(2) All specimens preloaded two cycles 10% over the creep stress.

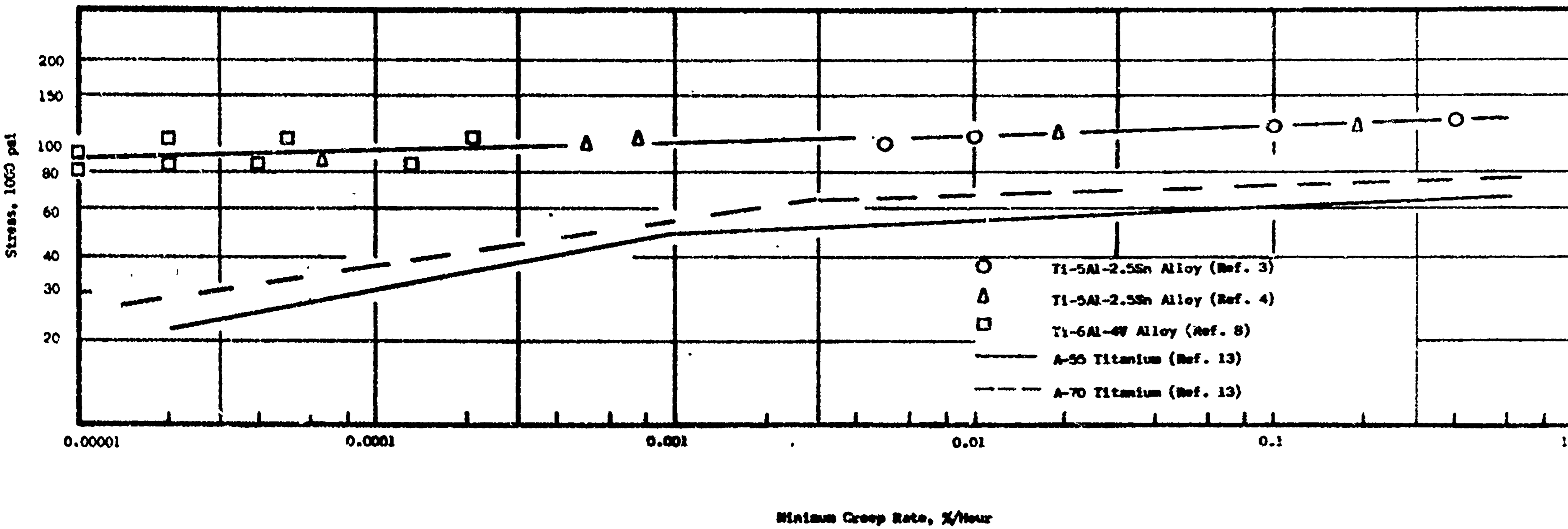

FIGURE 1. STRESS VERSUS MINIMUM CREEP RATE CURVES FOR Ti-5Al-2.5Sn, Ti-6Al-4V, A-55, AND A-70 TITANIUM ALLOYS AT ROOM TEMPERATURE

An investigation of relaxation properties of the Ti-6Al-4V alloy (heat treated) was carried out by Northrop Aircraft, Inc.[12] The tests indicated that no creep occurs at room temperature at a stress of 96,200 psi over a period in excess of 1200 hours. This, however, is a relatively low stress for the particular heat-treated condition used. Thus, the particular lot of material had an ultimate tensile strength of 171,500 psi, 0.2% offset yield strength of 162,500 psi, PL of 147,500 psi, 15% elongation, and 43% reduction of area at room temperature. Relaxation tests by Northrop[12] on the same lot of Ti-6Al-4V alloy at 0 F showed signs of relaxation (which results from creep) at an initial stress of 98,000 psi.

A summary of the available creep data on the Ti-5Al-2.5Sn and the Ti-6Al-4V alloys at room temperature is presented in Figure 1. Also shown in this figure, for comparison purposes, are creep rates for two grades of unalloyed titanium (A-55 and A-70). Minimum creep rates are not necessarily the best way to show creep strengths since they ignore primary creep. However, the creep rates are the best data available for showing comparative values of the various alloys.

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